Sediment Transport at Density Fronts in Shallow Water

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LONG-TERM GOALS

The goal of this research is to quantify through observations and modeling how density fronts in shallow estuarine flows impact the mobilization, redistribution, trapping, and deposition of suspended sediment.

OBJECTIVES

The objectives of this research program are to

- implement a high-resolution, 3-dimensional, finite-volume hydrodynamic model of tidal flats field site including advanced sediment transport algorithms,
- integrate and test a set of field instruments to measure density, velocity, and suspended sediment concentration at density fronts in shallow water (< 1 m),
- characterize flow and suspended sediment at a density front through the tidal inundation cycle as it travels across the intertidal zone, and
- combine the observations and model results to (1) quantify sediment suspension, trapping, and lateral circulation at the front and (2) evaluate and improve the sediment transport model.

APPROACH

Our research approach combines advanced observational and modeling techniques. In the field, we will measure velocity and suspended sediment at high resolution (~ few cm) in shallow flows, tracking the evolution of the salinity front through the tidal cycle. The instrumentation will incorporate an acoustic Doppler current profiler (ADCP) to measure currents and a profiling conductivity-temperature-depth sensor (CTD) to measure water column salinity and density. Suspended sediment concentrations will be based on a combination of acoustic and optical sensors. An acoustic backscatter sensor (ABS) will measure echo amplitude at three acoustic frequencies, and comparisons between the frequencies will provide information on the suspended particle size distributions. An optical backscatter sensor (OBS) associated with the CTD will provide additional data on the suspended sediment profile.

We will initially test and refine the shallow water survey system in the salt marsh and barrier beach system of Barnstable Harbor and Great Marsh on Cape Cod, MA. The primary field work will be conducted in June 2009 on the tidal flats at the mouth of the Skagit River in Puget Sound. We will coordinate the field work with other researchers in the Tidal Flats DRI, and to plan to integrate our focused, Lagrangian observations of the tidal density front with the larger scale arrays of moored

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instruments in the DRI. We will calibrate the acoustic and optical suspended sediment measurements from our surveys using sediment from the Skagit in test tanks at WHOI.

Numerical modeling of the Skagit tidal flats will complement the observational program. We will develop a model using the Finite Volume Coastal Ocean Model (FVCOM) and will incorporate recent advancements in sediment transport modeling through code from the Community Sediment Transport Model (CSTM). The unstructured grid of FVCOM allows the model to simulate conditions broadly across the Skagit flats and surrounding region, but with focused grid resolution near the observations. Using the observations, we will test how well the model resolves sharp salinity gradients at fronts, both across the tidal flats and at lateral fronts coinciding with channel-shoal bathymetry. We will use suspended sediment observations to evaluate the sediment transport algorithms, including for example how tidal asymmetry in the stratification and turbulence due to straining of the density front affects sediment resuspension and deposition. Collectively, analyses of the observations and model will provide evidence for how local frontal processes on scales of 10's to 100's of meters impact retention, redistribution, and export of sediment over tidal flats on scales of kilometers.

WORK COMPLETED

For the observational component of the research program, we have begun the design of the survey package and have placed orders the necessary instrumentation. We plan to start testing the instruments in the fall of 2008 or the spring of 2009, depending on when the instruments are delivered and can be prepared for use.

We have begun development and testing of a model of the Skagit tidal flats and surrounding region using FVCOM (Figure 1). We began with a relatively coarse mesh based on existing bathymetry (NOAA soundings and regional LIDAR surveys), and collected boundary condition data to force the model (water level, river discharge, open boundary salinity). Comparisons with available observations of water level, velocity and salinity on the Skagit flats are promising, but indicate that additional refinements to the model parameters (bottom friction, background diffusivity, boundary conditions) and the mesh are required prior to detailed analyses of the results. Currently, the model resolution is limited by a lack of high-quality bathymetry on the flats. Recent observations by participants in the Tidal Flats DRI will aid in the refinement of the bathymetry and allow for more realistic simulations. The model development will be iterative as more observations become available for comparison with the simulations.

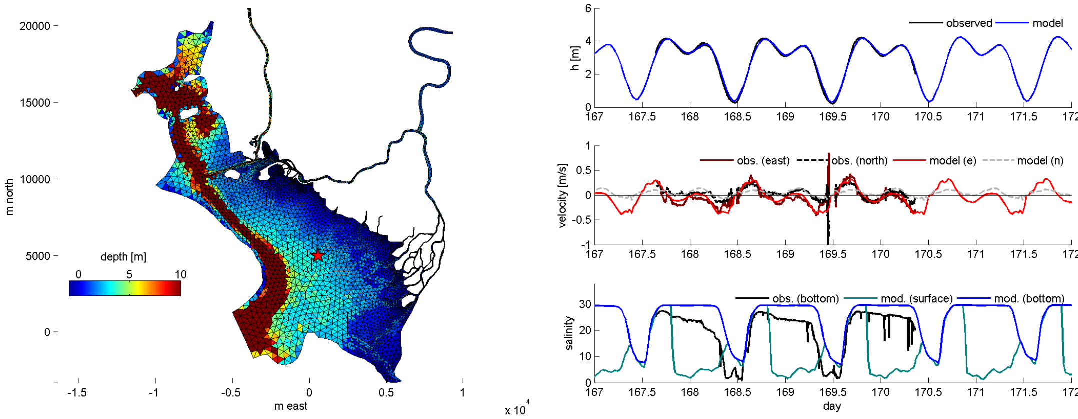

Figure 1. (left) Model mesh and bathymetry for the Skagit River tidal flats. (right) comparison of preliminary model results and observations of water surface elevation, velocity (east and north components) and salinity at a location on the tidal flats (marked with a star on the map).

RESULTS

This project is still in its early stages, but we have made preliminary progress in modeling flows over the Skagit tidal flats. Based on comparisons with observations, the barotropic tide is well represented in the model, and tidal velocities over the flats compare well in direction and magnitude (Fig. 1). The current grid resolution is too coarse to resolve the network of tidal channels through the flats, so local effects of the channels on velocities and salinities are not captured in the model. We will address this by incorporating new sources of bathymetric data and increasing the mesh resolution. While the horizontal resolution remains limited by bathymetry, we were able to adjust the vertical resolution and found that at least 20 model layers were needed to resolve the observed stratification in 1-2 m of water. Salinity and stratification on the flats have some notable discrepancies with the observations, and require additional analysis. The location of the tidal salinity front depends on the boundary salinity and bottom friction, but also depends on the bathymetry in the distributary network of the South Fork of the Skagit River, particularly the along-channel bottom slope. We need to refine the bathymetry and model mesh in this distributary region as well as on the tidal flats.

IMPACT/APPLICATIONS

Results from this project may be used to enhance morphological models of coastal regions near river mouths, with applications to environmental assessment for the Navy. Trapping and deposition of sediment associated with density fronts could introduce significant spatial and temporal variability in bed consolidation and bathymetric relief on tidal flats. The project will also help to evaluate the skill of coastal hydrodynamic models at resolving narrow density fronts, including the surface expression of such fronts that can be assessed with remote sensing observations.

RELATED PROJECTS

This project is closely related to the Tidal Flats DRI. Ralston is a co-PI on a related project led by Geyer (“Sediment Flux and Trapping on the Skagit Tidal Flats”), which is an observational program to study estuarine processes and sediment transport on the tidal flats at larger scales and over longer

(seasonal) periods. We are collaborating with other DRI researchers (e.g., Thomson, Chickadel) to refine the bathymetry of the Skagit flats, a critical component to modeling these shallow tidal flows. We are collaborating with modelers involved in the DRI (Signell, Cowles) to share in model development for the Skagit, and are utilizing sediment transport subroutines developed through the Community Sediment Transport Model funded by the National Oceanographic Partnership Program.